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Abstract — **In this paper we propose a semi-deterministic channel propagation model for VANETs (Vehicular Ad-hoc NETworks) called UM-CRT. It is based on CRT (Communication Ray Tracer) and SCME–UM (Spatial Channel Model Extended – Urban Micro) which are respectively a deterministic channel simulator and a statistical channel model. It uses a process which adjusts the SCME-UM model using relevant parameters extracted from CRT. In order to evaluate this new model, we incorporate it into the NS-2 network simulator. Our results show that UM-CRT is adapted to VANETs simulations as it approximates in a realistic manner channel propagation mechanisms while improving simulation time.**

*Keywords - **Radio Mobile Channel; VANETs; Physical Layer; SISO; MIMO; Channel Model; Network Simulator.***

I. Introduction

Vehicular Ad-hoc NETworks (VANETs) is a very promising research area interesting the scientific community, car manufacturers and mobile telephony operators. Indeed, inter-vehicular communication systems can be used to set up different applications in order to improve security or for commercial reasons. Because the set up of experimental VANETs would imply huge investments, the study of those networks by simulation is unavoidable. One of the major issues when using simulators concerns the taking into account of the vehicular environment and therefore the realistic modeling of the wireless propagation channel. Indeed, there are still several problems linked to the impact of the mobility and the traffic density on channel statistics yet to solve e.g. frequency correlation, amplitude distribution and Doppler power spectral density.

The vast majority of network simulators allows the simulation of nodes' mobility. However, the consequence of this mobility on the physical layer is most of the time treated in a simplistic and consequently not quite realistic manner. This can lead to erroneous results [1]. One finds very few effective and robust channel models which take into account the mobility and especially the transmission environment.

For mobile telephony there exist reliable channel models which are customizable according to the environment [2]. To the best of our knowledge, only few research works take into account the effects of the propagation model in VANETs simulations [1][3]. Moreover, only one work studies the improvements brought by the 802.11p standard [3] and shows the necessity of using a realistic propagation model for VANETs simulations. In parallel, one finds research works presenting deterministic channel models [4][5] which are based on ray-tracing or ray-launching methods which allow a realistic modeling of the channel. Unfortunately, these models require very high processing times.

As far as VANETs are concerned, deterministic channel models are not suitable because of the high mobility and the diversity of situations encountered. The study of the higher layers of the OSI model (in particular the Network and Application layers) requires a low simulation time (i.e. a couple of minutes) in order to allow statistical analyses on large simulation series. Moreover, in order to simulate VANETs efficiently, one must have a network simulator which takes into account the mobility associated with the modeling of the realistic physical layer and which is also efficient in terms of processing time.

To answer these issues, we propose a semi-deterministic channel model called UM-CRT. It is based on the statistical Spatial Channel Model Extended Urban Microcell [6] developed for the Beyond 3G technology (B3G) and a deterministic propagation simulator called Communication Ray Tracer (CRT) developed by the Xlim-SIC laboratory in Poitiers-France [12]. To evaluate it, we have integrated UM-CRT into the Networks Simulator 2 (NS2) simulator [7].

The rest of this paper is organized as follows. Sections 2 and 3 present respectively the SCME-UM model and the CRT simulator. In section 4 the implementation of the 802.11 standard is detailed. The framework of UM-CRT is explained in section 5. Section 6 is dedicated to the new model evaluation. Finally, section 6 concludes this paper and deals with future works.

II. The Spatial Channel Model Extended (SCME) Urban Microcell (UM) model

The SCME statistical channel model is an evolution of the 3GPP Spatial Channel Model (SCM) [8]. It has been developed within the European WINNER project [9] for the simulation of B3G systems. The SCM model is limited to the simulation of systems at 2GHz for a maximum transmission bandwidth of

5MHz. Its extension, SCME for SCM extended, allows for the simulation of systems at 2 and 5 GHz for a maximum transmission bandwidth of 100MHz [6].

SCM and SCME are so called geometric models for which scatterers are placed stochastically in the simulation scene. SCME considers N clusters of scatterers. Each cluster corresponds to a resolvable path. Inside each path there are M non resolvable sub-paths. A simplified diagram representing a Base Station (BS) antenna array and a Mobile Station (MS) antenna array with one cluster is presented in Figure 1.

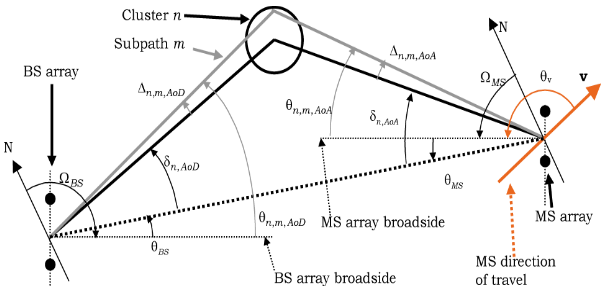

Figure 1 : Angular parameters of the SCME model

SCME is a natively Multiple Input Multiple Output (MIMO) model. Hence, for a BS antenna network constituted of N_T elements and a MS antenna network made up of N_R elements, the channel coefficients of the N multi-path components are given by a N_T x N_R matrix of complex coefficients obtained by the Sum of Sinusoids method [10]. These coefficients represent the channel impulse response. The details on how to implement the model and its key parameters are given in reference [6].

SCME allows for the simulation of three types of environments: Urban Microcell and Suburban Microcell (distance between MS and BS 3km maximum) and Urban Microcell (distance between MS and BS 1km maximum). In the context of VANETs, because of inter-vehicular distances less than a kilometer we have chosen the Urban Microcell (UM) environment.

The authors of reference [6] provide a Matlab implementation of the SCME model [11] which we have used in our simulations.

We now describe the way we have used this model. For a set of 90 distances chosen between 10 and 600 meters, we generate channel coefficients for two significant situations, namely a Line Of Sight (LOS) and a Non LOS (NLOS) communication. This criterion is used as a first approach to identify a significant parameter for the realistic modeling of the VANET propagation channel. In the SCME terminology a simulation of a defined duration is called a drop. We have used 40 second drops whose channel coefficients were stored in files for later use in the UM-CRT model which is described in section V.

III. The Communication Ray Tracer (CRT) Simulator

CRT is a deterministic propagation simulator developed by the Xlim-SIC laboratory in Poitiers [12]. CRT is based on a 3D ray-tracing technique for the searching of paths between two points in the network. Hence, for a chosen emitter-receiver link, it can determine all the existing paths in terms of delay, attenuation, phase and polarization according to the environment. In this way, we obtain a complete characterization of the narrow-band and wide-band channel and have a realistic approach of the multipath propagation mechanisms. CRT has been validated by several measurement campaigns [12] and will therefore be considered as our reference.

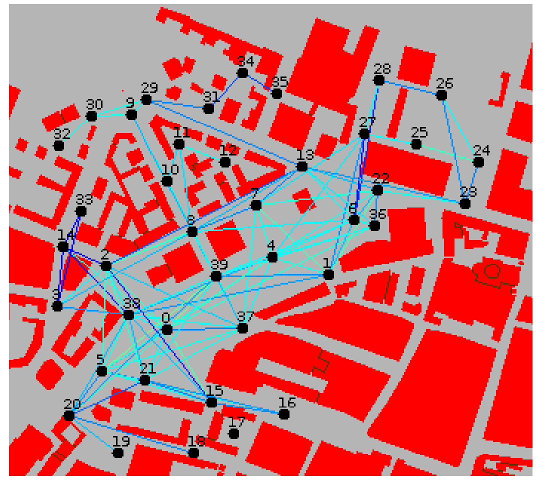

Figure 2 : CRT simulation of multiple communications in a realistic environment (Munich city center)

Figure 2 shows an example of VANETs communications in a typical urban environment using CRT. The CRT simulation procedure is as follows. Firstly, the user chooses a scene and places the communicating nodes into that scene. In a second stage, the nodes are associated with a moving trajectory. Then, according to a chosen distance resolution step, CRT calculates the channel impulse responses for all communicating nodes in the simulation scenario.

The drawback of this realistic simulation environment comes from the fact that it requires a quite huge amount of processing time. In the case of simulations with high mobility and/or with a high density of nodes (i.e. in most VANET situations), the simulation time is too high. For example, in a typical urban environment with 40 nodes moving during one minute, the calculation time can reach a fortnight. Indeed, since a communication is associated with each emitter-receiver couple according to its position, the calculation of the channel impulse response is made for each topological network modification. It seems to be obvious that such a simulator cannot be used as is in the case of VANETs with a large number of simulations.

IV. The 802.11 Physical layer

Having at our disposal channel impulse responses representing the channel behavior, we have to go a step further in order to characterize the communication's quality. The data transmitted in VANETs are digital. It is well known that the Bit Error Rate (BER) is a good indicator of the quality of a digital communication. Moreover, this indicator is closely related to the Packet Error Rate (PER) which is a quality indicator used in wireless networking. Therefore, in order to be as close as possible to the real situation, we have implemented the whole 802.11a (SISO) and 802.11n (MIMO) physical layers for all the throughputs supported by these standards. The implementation has been written in C++ using the IT++ library [13]. When these physical layers receive the impulse responses calculated either by SCME-UM or by CRT as input parameters, they produce BER values representing the communication's quality. Finally, the BER value calculated is made available via a software plugin to the network simulator NS-2 for use in the higher layers.

V. The UM-CRT semi-deterministic model

We have just presented two propagation simulators and their associated physical layers: one purely stochastic and the other purely deterministic, each having interesting characteristics for the simulation of VANETs, but none able alone to simulate efficiently for realistic reasons or processing time. This is the reason why we propose a semi-deterministic model which associates a deterministic propagation environment and a customizable statistical model permitting the reliable and fast simulation of VANETs.

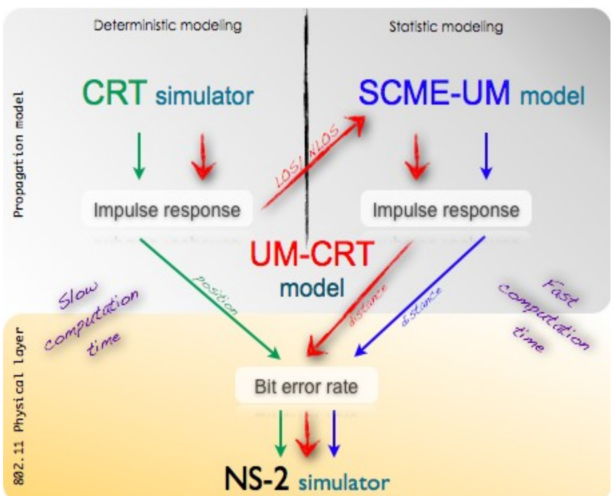

Figure 3: the UM-CRT model

Let us now describe the UM-CRT simulation procedure (refer to Figure 3). From the impulse response obtained with CRT, we determine if we are in a LOS or NLOS situation (see red/shadowed arrow on the upper center of Figure 3) and calculate the emitter-receiver distance. As mentioned in section II, the LOS-NLOS criterion is used as a first approach and we are currently working on the possibility to use more relevant criteria to characterize the VANET propagation channel. Using the two criteria mentioned before gives us an equivalent SCME-UM impulse response which has been precalculated for distances between 10 and 600 meters (see section II). Using this impulse response, we use the 802.11 physical layer to calculate the BER. This procedure allows decreasing significantly the simulation time. Indeed, if we had used only CRT we would have to calculate a BER for each new position. By considering the **distances** rather than the **positions** limits considerably the number of different possibilities and thus the number of BER calculations. In a VANET scenario, there can be a very large number of possible positions between two nodes, in contrast there is only a reduced number of distances between them.

The network simulator has now all the elements needed to describe a realistic transmission. For each communication and for each time NS-2 is going to connect with the 802.11 physical layer. According to the transmitter-receiver **distance** and the LOS or NLOS criterion NS-2 uses the BER obtained from the SCME-UM channel impulse response to characterize the communication. Hence, the semi-deterministic model simulates a realistic channel while permitting fast simulations.

VI. Evaluation of the UM-CRT model

To evaluate UM-CRT we compare it with CRT by simulating a typical urban environment: the Munich city center (cf. Figure 2). CRT will be our reference model. Note that the results of the statistical UM model are not presented here because they do not take into account a real propagation scene. Indeed, nothing allows us to determine if a path is LOS or NLOS. Therefore, the results will always either be perfect (100% of packets reach their destination) or bad (0% of packets reach their destination).

The simulations were performed in SISO and MIMO modes at a 5GHz frequency. In order to have some typical cases for comparing UM-CRT to CRT, we have varied the number of nodes (i.e. the number of vehicles), the number of simultaneous communications and the node positions. The routing protocol used was AODV. The traffic generated for inter node communications was UDP, the mobility was random and the nodes' speed was variable with time. All the simulations were performed on a Linux Mandriva system with an updated NS-2 2.29 version.

A first observation we make concerns the simulation time. With CRT, each VANET simulation lasts at least three days (equivalent to 40 second simulated time in NS-2). When using UM-CRT, the preprocessing stage is quite long but has to be done only once, and when the impulse responses are computed, the simulation time never exceeds 5 minutes for 40 seconds simulated time. This comes from the fact that BER computation is now based on the **distance** between nodes instead of their **positions** (see section V).

The comparison criteria between the CRT and UM-CRT models are the received packet rate and the mean hop count between a transmitter and a receiver. The more similar the results of semi-deterministic model are to the CRT model results, the more realistic the UM-CRT modeling. Please note that the presented analyses of results give only a trend and have no real statistical significance. This trend will have to be confirmed by further simulations. The configurations were chosen to be typical VANETs situations, namely:

1, 2, 3: 40 vehicles, 3 simultaneous communications and 0m/s, 4m/s or 8m/s speeds,

4: 10 vehicles, 3 simultaneous communications and 8m/s speed,

5: 40 vehicles, 1 communication and 8m/s speed.

For the SISO case, the simulations results are shown in Figure 4.

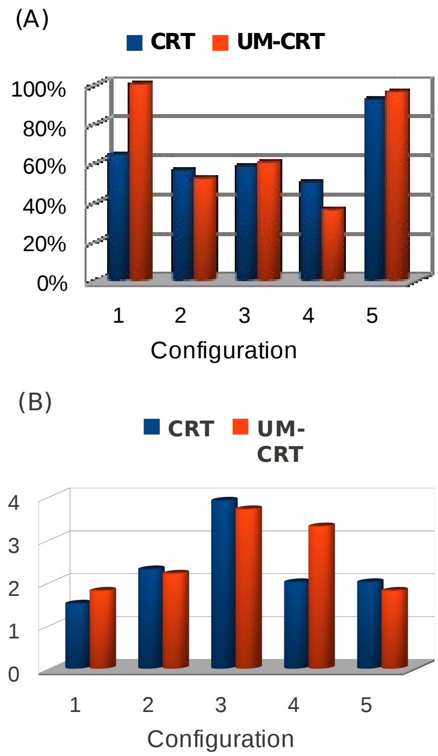

Figure 4 : Received packets rate (A) and mean number of hops (B) in the SISO case

Figure 4 shows that there are significant differences in terms of received packets rate (A) and mean number of hops (B) between CRT and UM-CRT for some simulations. We can notice that when the speed increases, the results between the two models become closer (configurations 2 and 3). Furthermore, when the number of nodes is small, the results between the two models disagree (configuration 4). This can be explained by the fact that when the speed is low or zero, the number of possible statistical outcomes is very small. UM-CRT is therefore lead by its statistical part and looses in realism. In the same way, in the case of a small number of nodes in the simulations, the number of outcomes is not large enough to emphasize the realism of the model.

We can also see that when the speed is increasing, the rate of received packets remains constant, but the mean number of hops increases. As the speed gets higher, the channel deteriorates and more hops are needed to achieve a reliable communication.

For the MIMO case, the results are presented in Figure 5. All the received packets rates on Figure 5 are better than in Figure 4. As expected, we can notice that a MIMO channel is more robust than a SISO one.
Figure 5 also confirms the tendencies observed in the SISO case. Indeed, when the number of nodes is important and the speed increases, the results between CRT and UM-CRT become very close.

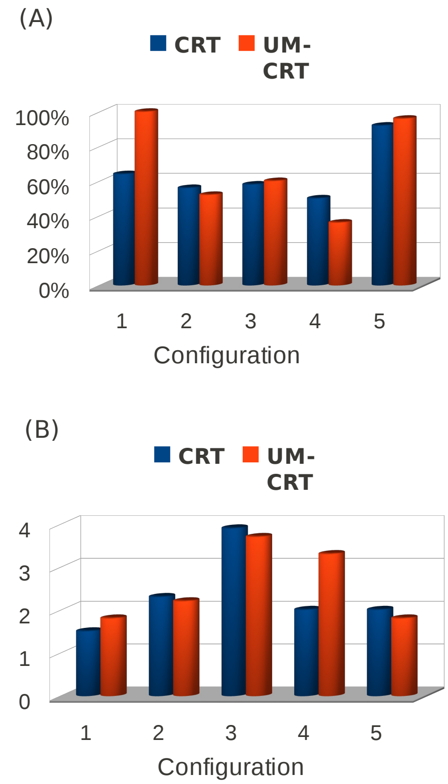

Figure 5 : Received packets rate (A) and mean number of hops (B) in the MIMO case

However, there is an exception for configuration 1 in which the results of the two models are very close whereas for higher speeds this is no longer the case (configurations 2 and 3). In fact, this is due to an improvement of the CRT model's robustness compared to the SISO case, leading to a received packet ratio of 100%.

The fact that the number of hops does not increase with speed is only due to the better robustness of the MIMO channel.

From these results, we can conclude that in simulations with low speeds or with a small number of nodes, the UM-CRT model is not realistic. But when the number of nodes becomes important, it is very close to reality. Moreover, when the node speed increases, the model accuracy comes close to the CRT deterministic model.

VII. Conclusion and future works

In this paper we have presented UM-CRT a semi-deterministic channel propagation model for VANETs. UM-CRT, which was integrated into the NS-2 network simulator is based on the stochastic SCME-UM model and the deterministic CRT channel simulator. The implementation of this new model requires a time-consuming preprocessing stage but allows afterwards to run network simulations in a very fast way. This makes it suitable for VANETs simulations having a large number of high mobility nodes. Moreover, our results show a trend for UM-CRT to be appropriate for fast and realistic vehicular networks simulations.

We currently focus our works on reducing the UM-CRT preprocessing time and on the selection of new relevant criteria extracted from the channel impulse response such as the RMS delay spread or the link capacity.

This work was supported by the French Agence Nationale de la Recherche (ANR) in the framework of the MOCAMIMODYN project.

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